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THE EFFECT OF AN ELECTRIC FIELD ON
SENSITIVITY OF PRIMARY EXPLOSIVES

MAURICE S. KIRSHENBAUM

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generally less than the dielectric breakdown strength of air. It was demonstrated that the initiation of the pressed, dextrinated lead azide could not be solely due to bulk Joule heating but also involved an electric field effect.

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INTRODUCTION

The generation, transport, build-up, and relaxation of electrostatic charge during the handling and processing of explosives have long been of concern because accidental explosions could be initiated by electrostatic discharge. Earlier experiments carried out in this laboratory (Ref 1,2) indicated that the common primary explosive, lead azide, may be sensitized by exposure to constant electric fields. That is, it may be more sensitive to an electrostatic discharge after previous exposure to sub-threshold electric fields. Other investigators (Ref 3,4) have also reported that the electrostatic sensitivities of lead styphnate and lead azide increase after repeated exposure to low-level electric fields. Sushkin et al. (Ref 5) reported that lead azide undergoes partial decomposition in an electric field, but did not report sensitization by the field. A possible result of sensitization by sub-threshold electric fields is the occasional explosions of detonators containing lead azide and lead styphnate, which occur shortly after manufacture.

The present work was undertaken to assess the hazards involved in handling or storing primary explosives that result from the exposure to electric fields. The program consisted of:

1. Determining the effect of previous exposures to pulsed electric fields on the electrostatic sensitivity of RD1333 lead azide powder.
2. Determining the effect of previous exposures to sub-threshold initiation levels of constant electric fields on the electrostatic sensitivity of RD1333 lead azide and tetracene powders.
3. Determining the prebreakdown current flowing through primary explosive powders as a function of time of application of a sub-threshold, constant electric field.
4. Determining the prebreakdown current flowing through pressed, dextrinated lead azide as a function of the time of application and the voltage of sub-threshold, constant electric fields.
5. Determining the effect of the density and thickness of pressed, dextrinated lead azide wafers on the electric field strength required for initiation.

EXPERIMENTAL

Apparatus

The parallel-plate, fixed-gap apparatus (Ref 6) was used for the electrostatic sensitivity measurements and the pulsed electric field experiments. The apparatus (Fig 1) was modified to apply constant electric fields to the samples by adding a double-pole, double-throw switch to the electric circuit. The switch disconnected the capacitor and the triggering circuits and connected the electric field directly to the electrode assembly. The circuitry for the electric field experiments consisted of a regulated d.c. power supply, a Singer electrostatic voltmeter (Model ESD-10) to measure the output voltage and a Keithley Model 610C electrometer to record the current through the explosives. A 10^8 ohm current-limiting resistor was placed in series with the explosive sample (whose resistances were in the 10^{12} ohm range) to protect the electrometer from the large transient current which occurs on detonation of the explosive or on gap breakdown. The resistor limited the maximum current flow to the microampere range. The apparatus could also be used either in the parallel-plate or the needle-plane electrode configuration for powder and pressed explosives. The various explosive-electrode geometry configurations are shown in Figure 2.

Materials

RD1333 lead azide: Lot Number OMC 2-2

Dextrinated lead azide: Lot Number OMC 68-14

Basic lead styphnate: Lot Number OMC 67-2

Tetracene: Lot Number OMC 67-18

The explosive powders were stored in dessicators over anhydrous CaSO_4 for at least 24 hours prior to test. The firing chamber was maintained at $35 \pm 5\%$ relative humidity by continuously passing dry air through the chamber.

Procedures

1. Pulsed Electric Field

The parallel-plate geometry (Fig 2b) with an interelectrode gap of 0.19 mm was used for the pulsed electric field experiments. An explosive powder sample, 6 to 8 mg, was placed in a sample holder consisting of a 4.8 mm diameter hole in a disc of a 0.19 mm thick polyvinyl chloride electrical tape on a 1.9 cm diameter flat steel disc.

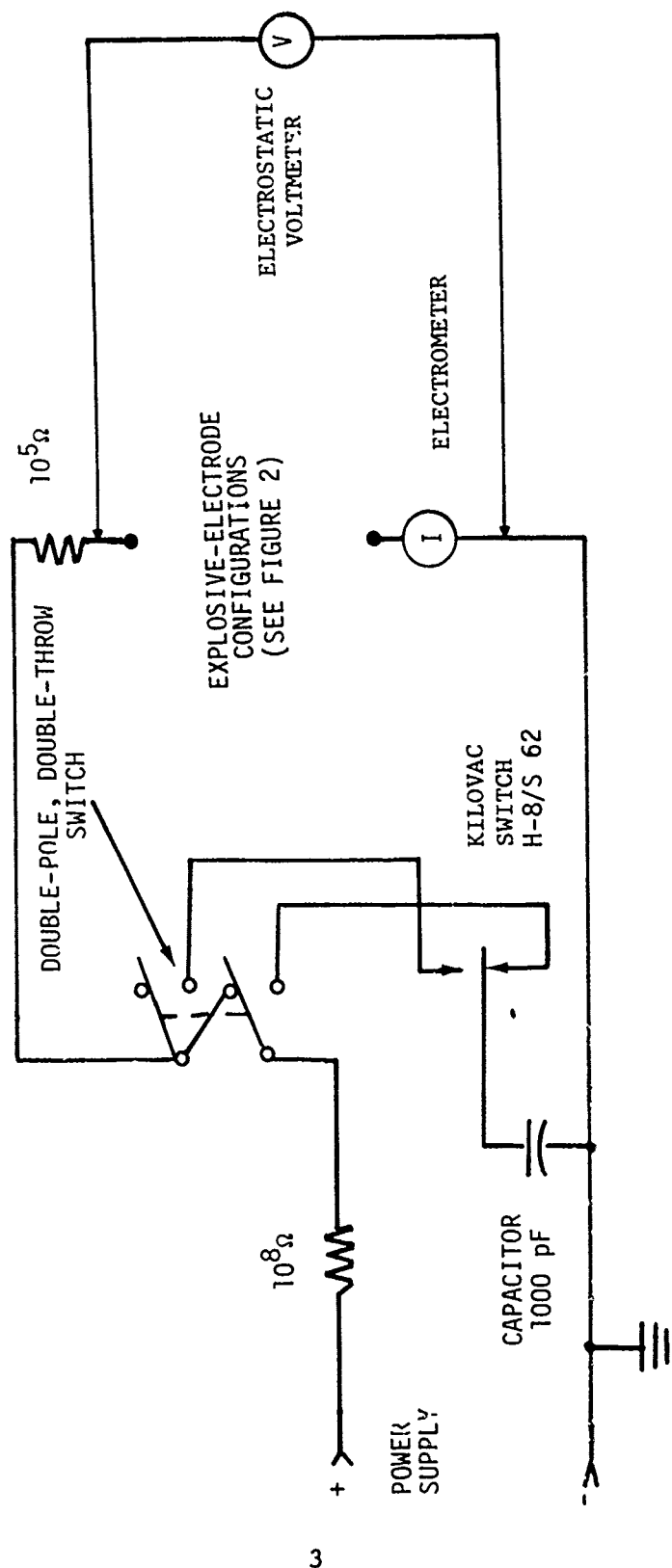


Fig 1 Test arrangement

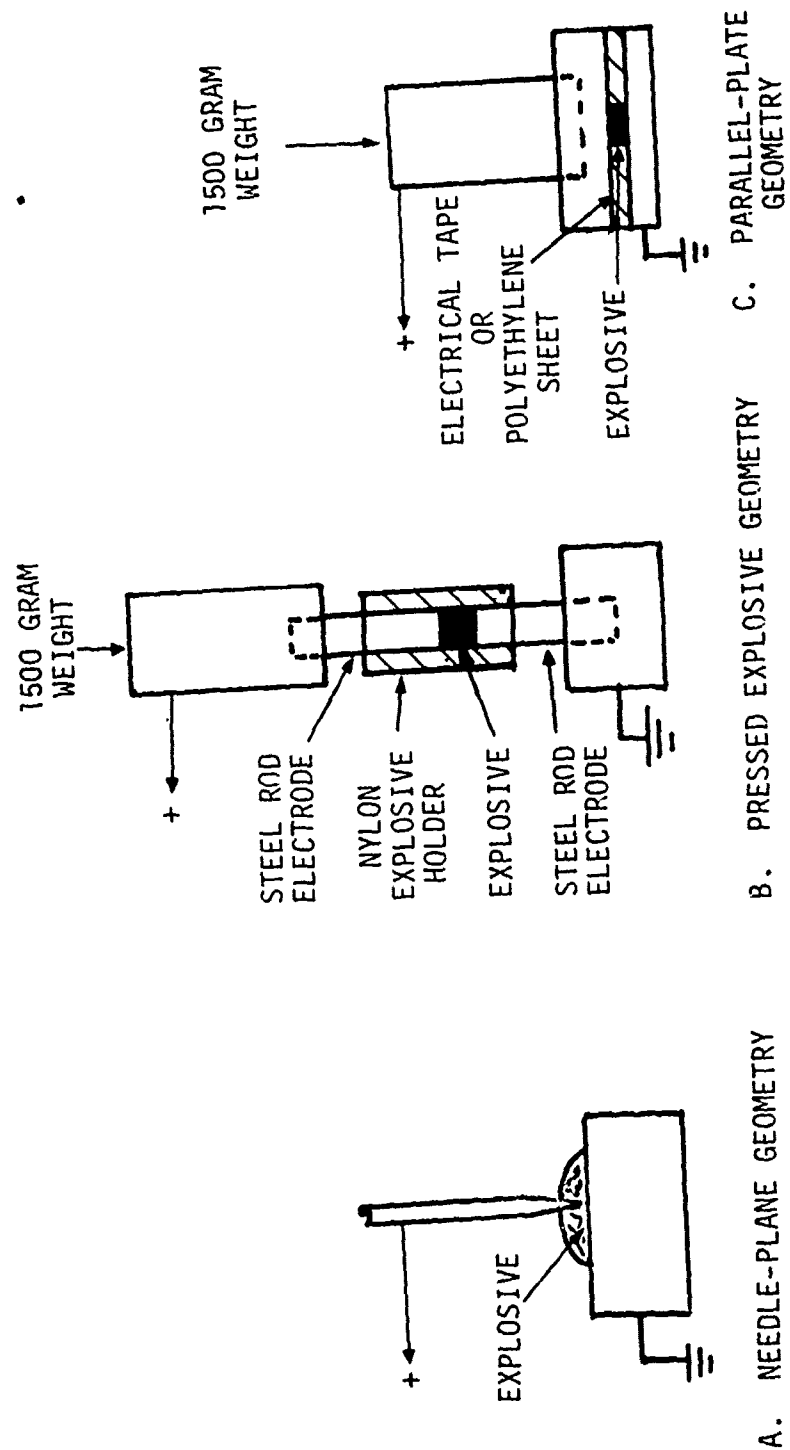


Fig 2 Explosive-electrode geometry configurations

After being tapped gently so that the powder completely covered the bottom and distributed itself evenly across the hole, the sample holder was placed on the base electrode, the cathode. The upper electrode, the anode, was lowered so that the gap length was the thickness of the tape (0.19 mm). A 1500 gram weight was applied to the upper electrode to assure good contact between the parallel-plate electrodes and the explosive sample. The pulse shape was formed by discharging a charged, high voltage, extended foil capacitor through a carbon film resistor. Each explosive sample was subjected to a specified number of capacitor discharges unless prior explosion occurred. The number of discharges required for explosion was recorded.

2. Constant Electric Field - Explosive Powder

Both the needle-plane (Fig 2a) and the parallel-plate (Fig 2b) configurations were used for the electric field studies. In the needle-plane electrode experiments, the gap length was varied from 0.25 mm to less than 0.025 mm. The weight of the explosive sample was varied from 6 mg to less than 1 mg. The interelectrode gap was 0.19 mm in the parallel-plate electrode experiment (see Procedure 1). Each explosive sample was subjected to an electric field for known amounts of time, either continuously up to several hours or in several cycles of one-minute-on, one-minute-off or ten-minutes-on, ten-minutes-off application of voltage. The current was monitored continuously.

Any change in the electrostatic sensitivity was determined immediately after the electric field exposure by determining the new minimum initiation energy value. The minimum value was found by reducing the voltage across the storage capacitor in 200 V increments until no initiation was obtained in 25 test samples. The apparatus was converted to the electrostatic sensitivity apparatus by means of the double-pole, double-throw switch without disturbing the sample (Fig 1).

3. Constant Electric Field - Pressed Explosive

To prevent breakdown in air and to minimize surface currents, the explosive powder was pressed into a nylon sleeve between two 0.48 cm diameter, flat surfaced steel rods with rounded edges. The consolidation took place in a Kent press using a 20-second dwell time. The explosive was pressed to five different densities, ranging from 2.7 to 3.75 g/ml, and for four wafer thicknesses, varying from 0.04 to 0.12 cm. The density of the pressed wafer was determined from a density-loading pressure nomograph. The thickness of the pressed wafer was determined by calculating the difference of the overall length of the two steel

rods in the nylon sleeve measured before and after the explosive powder was added to the sleeve and consolidated. The two steel rods also served as the electrodes when the loaded assembly was placed in the electric circuit. A 1500-gram weight was applied to the upper electrode to maintain good contact between the electrodes and the explosive wafers.

The explosive containing assembly was subjected to one-minute-on, one-minute-off applications of voltage, increasing the voltage in 100 V increments until the sample exploded. For each value of voltage the potential was increased to the one minute dwell value from zero in 5 seconds and decreased very quickly after the one minute dwell. The current was monitored continuously. The average electric field (kV/cm) was calculated by dividing the applied voltage by the sample thickness.

RESULTS

Effect of Pulsed Electric Fields on the Electrostatic Sensitivity of RD1333 Lead Azide

Three series of tests were carried out in the parallel-plate electrode geometry (see Procedure 1) to determine the change in the electrostatic sensitivity of RD1333 lead azide powder due to previous exposure to pulsed electric fields. One-hundred samples were tested in each of two series of tests and twenty-six samples were tested in the third series. For each sample in the first two series, capacitor discharges were continued until explosion occurred or the sample received ten discharges. Each of the twenty-six samples in the third test was exposed to a maximum of five capacitor discharges. The samples initiated out of the samples tested for the specified number of capacitor discharges are shown in Table 1. The values for the first capacitor discharge (line 1) represent the results obtained for no previous electric field exposure. A statistical analysis of the data based on comparing observed proportions in a random sample of normal distributions (Chapter 8 of Ref 7) show that at the 90% confidence level there was no increase in the electrostatic sensitivity of RD1333 lead azide due to previous exposure to pulsed electric fields.

Effect of Constant Electric Fields on the Electrostatic Sensitivity of RD1333 Lead Azide and Tetracene

RD1333 lead azide powder was subjected to three different electric field conditions just prior to the electrostatic sensitivity measurements to determine whether there was a change in the electrostatic sensitivity of the exposure due to previous exposures to sub-threshold initiation levels of constant electric fields. In the first test, the

Table 1
Response of RD1333 lead azide to pulsed electric fields

Number of capacitor discharges	Percent (fraction) samples initiated		
	Test No. 1 ^a	Test No. 2 ^b	Test No. 3 ^c
	<u>No previous exposure</u>		
1	32 (32/100)	15 (15/100)	19 (19/26)
<u>With previous exposure</u>			
2	31 (21/68)	8 (7/85)	5 (1/21)
3	19 (9/47)	13 (10/78)	10 (2/20)
4	16 (6/38)	7 (5/68)	11 (2/18)
5	16 (5/32)	6 (4/63)	12 (2/16)
6	22 (6/27)	5 (3/59)	--
7	10 (2/21)	11 (6/56)	--
8	11 (2/19)	4 (2/50)	--
9	29 (5/17)	6 (3/48)	--
10	17 (2/12)	4 (2/45)	--

a C = 3000 pF, R = 56 ohms, V = 4000 V, gap length = 0.19 mm; 100 samples, maximum 10 discharges per sample
b C = 3000 pF, R = 56 ohms, V = 3500 V, gap length = 0.19 mm; 100 samples, maximum 10 discharges per sample
c C = 500 pF, R = 100 kilohms, V = 4500 V, gap length = .25 mm; 26 samples, maximum 5 discharges per sample

samples were subjected continuously for one-hundred minutes to an electric field strength of 64 kV/cm. In the second test, the samples were subjected to the electric field in six cycles of a one-minute-on, one-minute-off application of voltage. The time of the six cycles was increased to ten-minutes-on, ten-minutes-off in the third test. Electric fields larger than 64 kV/cm were not used because larger electric fields sometimes resulted in gap breakdown. The parallel-plate electrode configuration (Fig 2b) was used in all the tests.

The minimum initiation energy value measured after continuous exposure was the same as the value obtained before the exposure (control), 4100 ergs (1000 pF capacitor charged to 2600 V). A minimum value of 2900 ergs (1000 pF capacitor charged to 2200 V) was obtained after both the one minute and the ten minute cycles. Hence, the tests show that RD1333 lead azide was more sensitive after both of the six cycle applications of voltage but was not affected by the 100 minute continuous exposure.

To determine the change in the electrostatic sensitivity of tetracene powder due to previous exposure to sub-threshold, constant electric fields, the explosive was subjected to an electric field strength of 64 kV/cm in six voltage cycles of one-minute-on, one-minute-off. The minimum initiation energy value decreased from 6100 ergs (1000 pF capacitor charged to 3200 V) (control) to 5400 ergs (1000 pF capacitor charged to 3000 V). Tetracene may have become slightly more sensitive after the six cycle electric field exposure, but the results are inconclusive.

Current Measurements - Explosive Powder

Hanna and co-workers (Ref 3,4) reported that basic lead styphnate and RD1333 lead azide have the ability to store quantities of energy below the detonation threshold in a cumulative manner and to retain an elevated state of conductivity over a period of time after the applied potential had been removed. Thus, when a voltage (30 to 2000 V) was applied to a sample of either basic lead styphnate powder (<0.025 mm thick) or RD1333 lead azide powder (0.13 to 0.25 mm thick) held between a needle and a plane electrode, the sample would become conductive after a short period of time and current would start to flow through the explosive. With no further increase in the voltage, the current, which was in the microampere range, would increase exponentially with time, and if the voltage was maintained, the sample would explode after several minutes. If the voltage was turned off for several minutes and then turned back on, the current flow would immediately return to its elevated value and continue its exponential increase until the sample exploded. They concluded that the electrostatic sensitivity of the two explosives

increased with continued or sequential exposure to small quantities of voltages.

In the present study, an experiment was conducted to determine any change in the prebreakdown current flowing through basic lead styphnate, RD1333 lead azide, dextrinated lead azide, and tetracene as a function of time of application of constant, subthreshold electric fields near the initiation levels. The explosive powders were tested in the parallel-plate electrode configuration subjected to the various electric field conditions listed in Table 2. No significant change in the prebreakdown current was observed when gap breakdown did not occur. Tests conducted with the needle-plane electrode geometry under similar electric field conditions also showed negligible prebreakdown current changes. If gap breakdown did momentarily occur during the exposure, however, then the prebreakdown current gradually increased during the exposure. It was observed that, when a dextrinated lead azide sample (sandwiched between parallel-plate electrodes) was subjected to an electric field strength of 80 kV/cm, the gap broke down several times during a 300-minute exposure. No explosion or initiation resulted from the gaseous discharges upon gap breakdown. The prebreakdown current gradually increased from 1×10^{-9} to 2.4×10^{-9} ampere during the 300-minute exposure. Continuing the exposure overnight resulted in the explosive sample shorting out and examination of the sample revealed black particles, the size of a pinpoint, throughout the sample thickness.

Since no appreciable prebreakdown current increase was observed in any of the experiments in the present study when the gap did not break down, an experimental effort was made to reproduce the test arrangement as described by Hanna and co-workers. In these simulated tests, the gap or the explosive length was varied from 0.13 mm to <0.025 mm. The applied voltage was varied from 300 to 2000 V and the maximum voltage used in each test depended upon the gap length and the threshold voltage for gap breakdown. It was observed that the prebreakdown current began to flow through the explosive sample after the applied voltage reached a certain value. The current was in the 10^{-9} to 10^{-10} ampere range when the gap length was just long enough to prevent gap breakdown for the applied voltage. Even when the gap was reduced to less than 0.025 mm and the voltage exposure lasted up to 60 minutes, no significant current increase was recorded in any of the experiments with either basic lead styphnate or RD1333 lead azide. If the gap was reduced very slightly or the applied voltage was increased very slightly, gap breakdown would occur. Gap breakdown was recognized by a sharp rise in current to the microampere range accompanied by an abrupt and very large drop in the

Table 2

Electric field test conditions

<u>Explosive powder</u>	<u>Electric field strength</u> (kV/cm)	<u>Type of exposure</u>	<u>Length of exposure</u> (minutes)
Basic lead styphnate	80	Continuous	200
	95	Continuous	15
	105	Continuous	41*
	58	10 cycles	One-on, one-off
	80	10 cycles	Five-on, five-off
	72	2 cycles	Twenty-on, twenty-off
RD1333 lead azide	30	Continuous	250
	56	8 cycles	One-on, one-off
	56	8 cycles	Ten-on, ten-off
	56	(10 cycles	One-on, one-off)
	Combination	(Continuous	200)
		(6 cycles	One-on, one-off)
Dextrinated lead azide	56	Continuous	150
	56	35 cycles	One-on, one-off
	56	Combination(6 cycles	One-on, one-off)
		(Continuous	290)
Tetracene	64	Continuous	220
	64	8 cycles	Ten-on, ten-off

* Sample exploded after 41 minutes; no prebreakdown current change was noted after 40 minutes, the last current reading recorded.

potential between the electrodes.¹ The gaseous discharges (gap breakdowns) occurred at rates of less than one per minute to greater than thousands of times a second, depending upon the over-voltage. No change in the prebreakdown current was noted prior to any gap breakdown. The explosives did not always initiate and explode upon gap breakdown, even after numerous gaseous discharges. The frequency of explosion depended upon the applied voltage and the current, which was controlled by the current limiting resistor. Adjusting the applied voltage and the gap length back to their original values, returned the system to the original current flow of 10^{-9} to 10^{-10} ampere. These results do not reproduce these reported by Hanna and co-workers (Ref 3,4).

Current Measurements - Pressed Dextrinated Lead Azide

An effort was made to determine the change in the prebreakdown current flowing through pressed dextrinated lead azide as a function of time of application of a constant, electric field near the initiation level. Two 0.081 cm-thick wafers (pressed to a mean density of 2.95 g/ml) were subjected to an electric field strength of 42 kV/cm. One wafer exploded after 4 1/2 minutes. No current increase was noted prior to the explosion. The second specimen was exposed for 75 minutes and no appreciable current change was recorded. The current gradually increased from 1.6×10^{-9} to 1.9×10^{-9} ampere during the exposure.

A third wafer was exposed to a 46 kV/cm electric field. The prebreakdown current was 2.2×10^{-9} ampere. After the azide wafer had received a 200-minute exposure without a significant current change, the electric field was reduced to zero and the test was discontinued for the day. The azide wafer was left undisturbed in the test chamber overnight. The next day, 16 hours later, the electric field strength was gradually raised from zero back to 46 kV/cm in 1 1/2 minutes. The prebreakdown current was 1.5×10^{-9} ampere. Four and one-half minutes after the 46 kV/cm electric field strength was attained, the sample exploded. No current increase was observed prior to the explosion.

A study of the current-voltage characteristics of pressed dextrinated lead azide was carried out at voltages below and near the initiation condition described in the previous section. It was observed that the prebreakdown current began to flow through the azide wafer after the electric field reached a certain field

¹The maximum current during gap breakdown was in the micro-ampere range due to the 10^8 ohm current limiting resistor in series with the gap.

strength. Increasing the applied voltage (electric field), increased the current. The dependence of the prebreakdown current on the applied voltage is shown in Figures 3 to 5. The least square fit was used to draw the straight line plots. The current at the end of one minute, although not strictly steady state, was taken to represent the response of the sample to the applied voltage. An initial current spike, observed immediately upon application of the voltage, was attributed to the inherent capacitance in the external circuit and not the current through the sample.

The resistivity of the pressed azide wafers with steel electrode contacts, calculated for wafers of different density and thickness, ranged from $1-4 \times 10^{12}$ ohm-cm. The resistivity was calculated from the resistance and dimensions of the wafer according to the following equation:

$$\rho = \frac{RA}{t}$$

where ρ is the resistivity of the wafer in ohm-cm

R is the resistance of the wafer in ohms

A is the cross-section area of the wafer in cm^2

t is the thickness of the wafer in cm

The resistance of the wafer was determined from the slope of the plots (Fig 3-5) which followed Ohm's law.

Electric Field Strength for Initiation of Dextrinated Lead Azide

A series of experiments was conducted to determine what effect the density and the thickness of the pressed dextrinated lead azide wafer have on the electric field strength required for initiating the explosive. The explosive was subjected to one-minute-on, one-minute-off application of voltage, increasing the voltage in 100 V increments until the sample exploded. The calculated mean electric field strengths, the standard deviations, and the standard errors of the means are shown in Table 3. The mean electric field strengths varied from 37 to 77 kV/cm. The mean values were plotted as a function of the density (Fig 6) and thickness (Fig 17). Each point on the curves represents an average of 3 to 23 samples (Table 3). The dielectric breakdown strength for air in the same test configuration is also shown in Figure 7 as a comparison. The experimental data show that the electric field strength for initiating explosion was a function of the thickness, essentially independent of the density when the pressed wafers were 0.04 to 0.08 cm thick, and generally less than the dielectric breakdown strength of air.

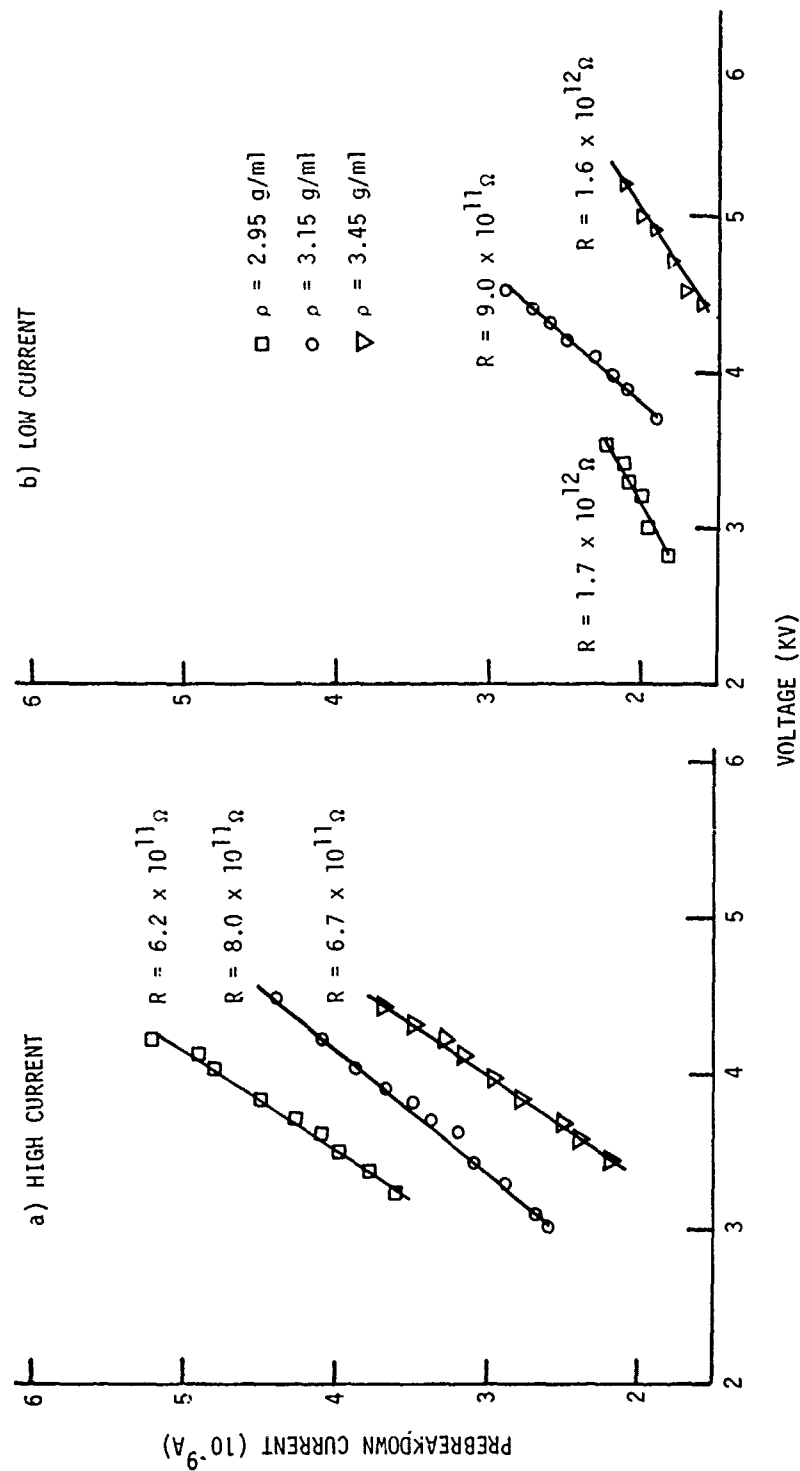


Fig 3 Current-voltage characteristics of 0.080-cm-thick dextrinated lead azide wafers

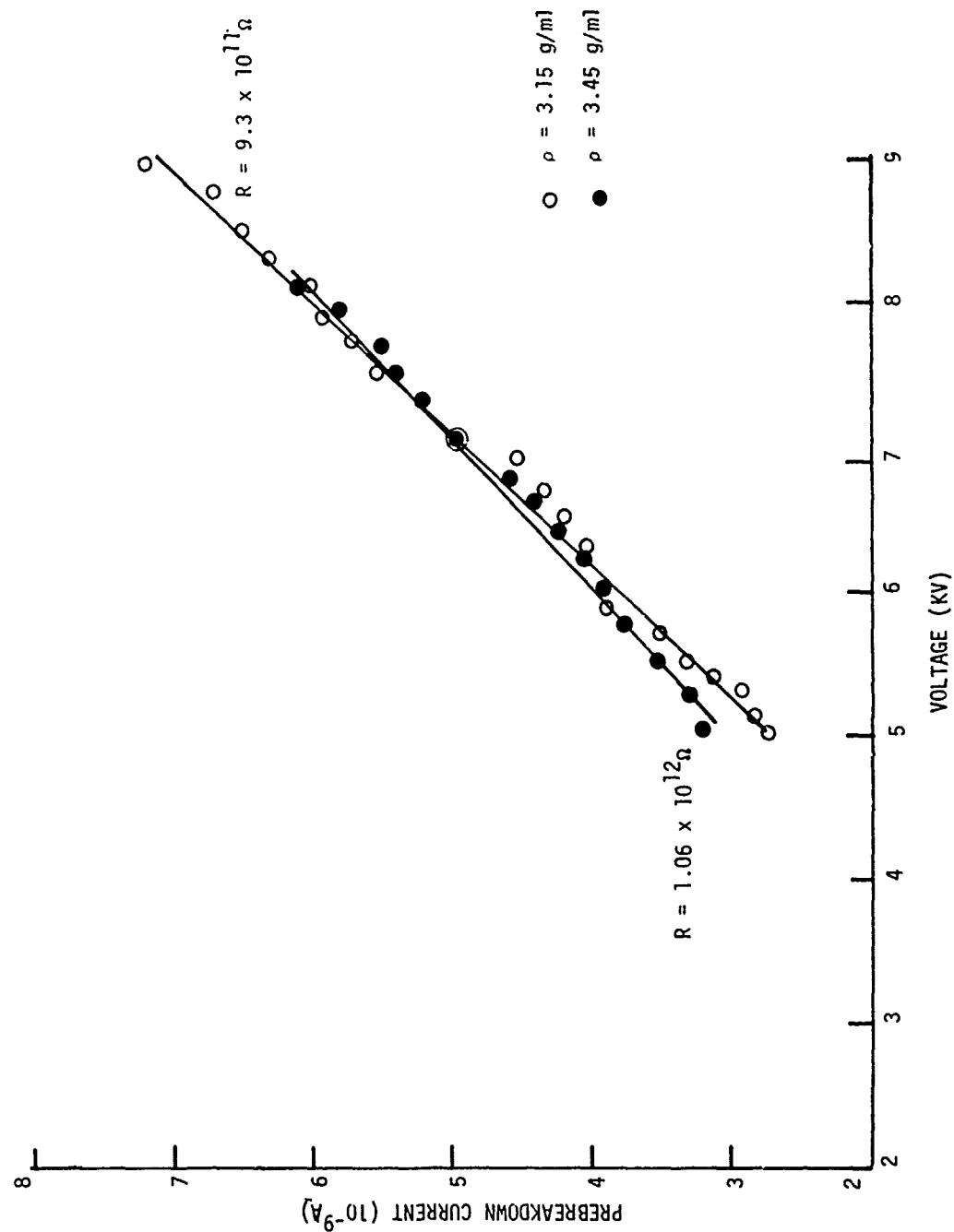


Fig 4 Current-voltage characteristics of 0.11-cm-thick dextrinated lead azide wafers

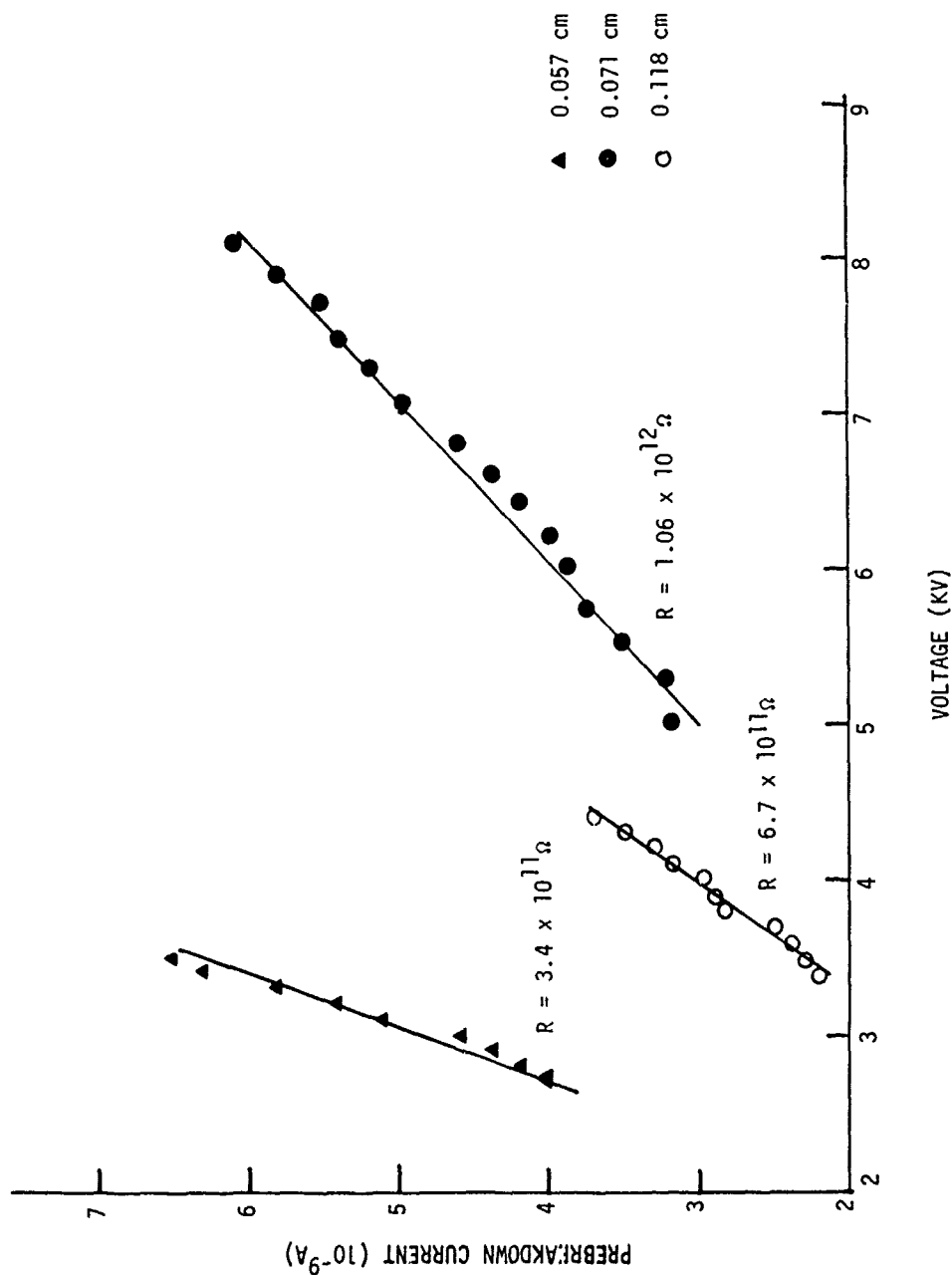


Fig 5 Current-voltage characteristics of pressed dextrinated lead azide (density = 3.45 g/ml)

Table 3

Electric field strength for initiating dextrinated lead azide

<u>Density</u> (g/ml)	<u>Thickness</u> (cm)	<u>Mean electric field strength</u> (kv/cm)	<u>Standard deviation</u>	<u>Standard error of the mean</u>	<u>Number samples tested</u>
2.7	0.042	50.3	0.32	0.19	3
	0.052	41.3	3.46	1.55	5
	0.080	41.4	3.40	1.52	5
	0.108	36.9	2.13	0.95	5
2.95	0.044	46.5	3.48	1.00	12
	0.053	47.6	3.99	1.11	13
	0.082	43.9	4.83	1.01	23
	0.107	47.4	4.16	2.08	4
3.15	0.041	52.7	3.34	1.11	9
	0.056	49.2	3.59	0.80	20
	0.076	54.8	4.26	1.29	11
	0.110	77.4	4.65	2.33	4
3.45	0.044	44.5	3.80	1.15	11
	0.056	48.5	1.79	0.60	9
	0.083	53.0	4.45	1.41	10
	0.116	64.9	6.04	2.70	5
3.75	0.045	41.8	4.84	1.98	6
	0.056	44.4	5.92	2.65	5
	0.082	51.3	3.00	1.50	4

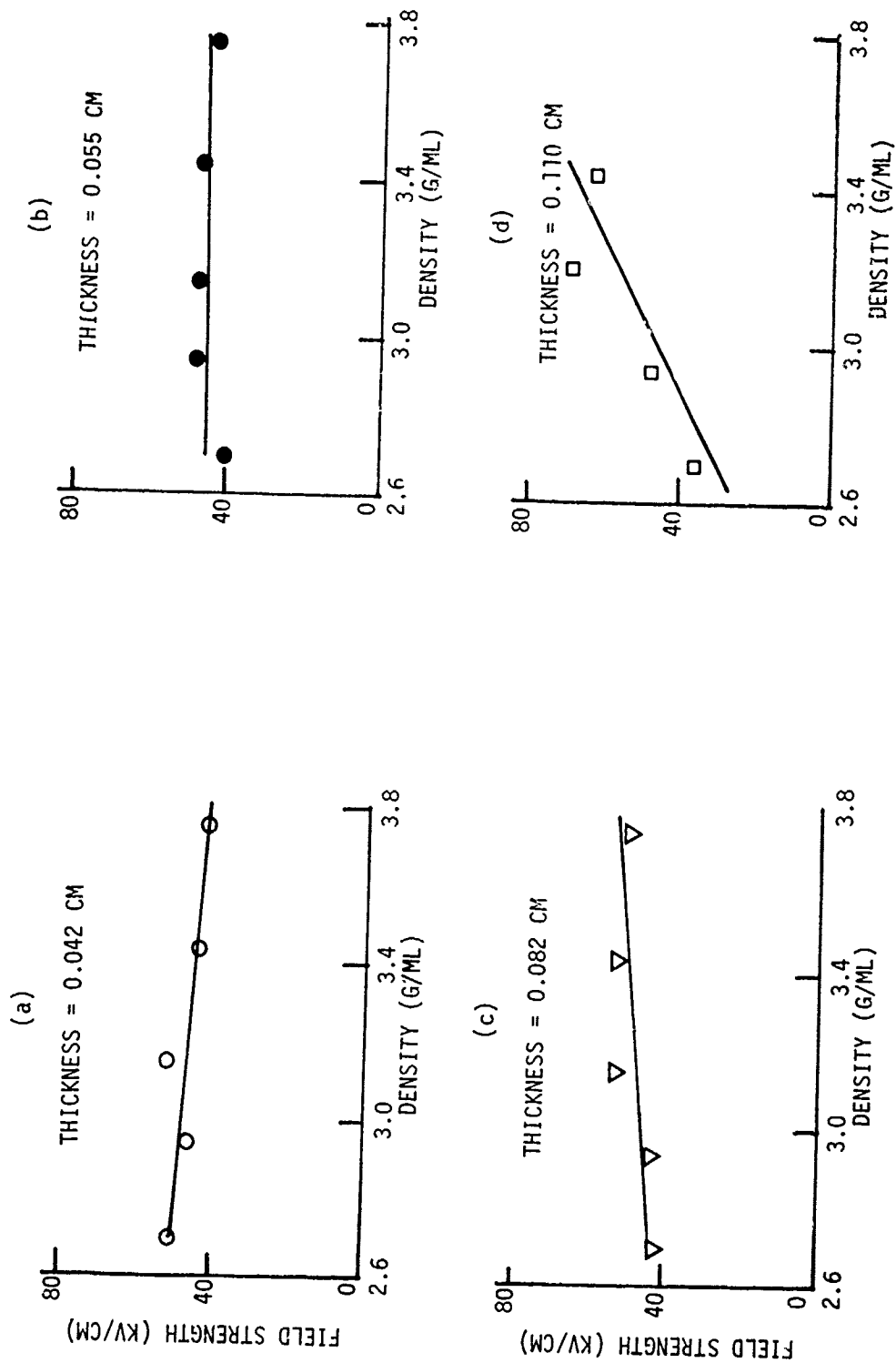


Fig 6 Dependence of electric field strength for initiation on density of dextrinated lead azide wafer

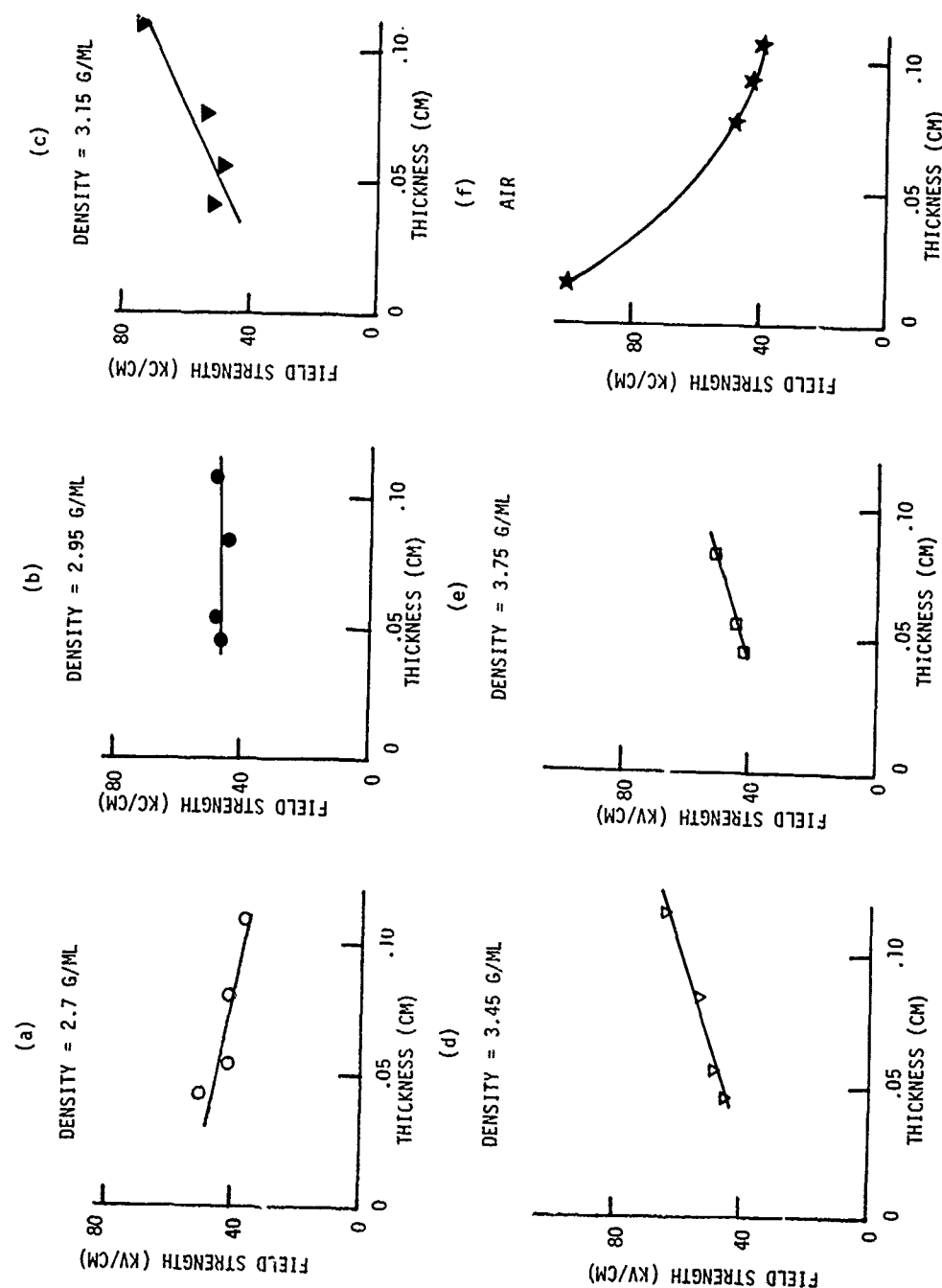


Fig 7 Dependence of electric field strength for initiation on thickness of dextrinated lead azide wafer

Explosion did not always occur immediately upon application of the voltage. Delay times varied from zero to 60 seconds. Thin, low-density wafers did not always explode upon breakdown. This breakdown without explosion occurred in several 0.04-cm-thick wafers, pressed to a density of 2.7 g/ml.

DISCUSSION

Current Measurements - Explosive Powder

No significant prebreakdown current increase was obtained in the experiments which tried to reproduce the test arrangement described by Hanna. The "memory" phenomenon reported by Hanna was not observed, although the gap length was reduced to less than 0.025 and the explosive samples were exposed to electric field strengths up to the initiation levels for as long as 60 minutes. The current remained in the 10^{-9} to 10^{-10} ampere range. It is noteworthy that Downs and co-workers (Ref 2) reported that the magnitude of the prebreakdown current and the current just prior to explosion ranged from 10^{-8} to 10^{-9} ampere when single crystals of lead azide (0.19 to 0.76 mm thick) were subjected to electric field strengths below and near the initiation level. One possible explanation apparent at this time for the large current values (microamperes) obtained by Hanna and co-workers may be that the measured values were the current flowing during gap breakdown rather than the prebreakdown current flowing through conducting explosive. It is interesting to note that the current calculated for Hanna's test arrangement is approximately equivalent to his reported values if it assumed that the gap was shorted. In the present study, microampere current values were only observed during gap breakdown.

In some of the experiments reported in References 3 and 4, the explosive was added to the gap after the air gap was adjusted so that the air gap was just long enough to prevent gap breakdown for the applied voltage. In other experiments, the explosive was added to the gap and then the gap length was adjusted until it was believed that the length was just long enough to prevent gap breakdown for the applied voltage. The gap length in other tests was too small to measure, less than 0.0025 mm. It should be noted that the presence of powder in a gap between a needle and a plane lowers the threshold voltage required for gap breakdown (Ref 6). The time to gap breakdown, with or without powder in the gap, could be of the order of seconds to minutes when the applied voltage is equal to or only a little greater than the threshold for gap breakdown. Once breakdown occurs, gaseous discharge

could continue at a fast rate. The resistance of the gap during breakdown is not zero and could become lower after several gaseous discharges. This was demonstrated in the present study for an air gap and for a gap with explosive by showing that the current gradually increased several microamperes after several gaseous discharges. In view of the above, it is believed that the increasing current, in the microampere range, noted by Hanna and co-workers may have been due to breakdown of the gap.

Current Measurements - Pressed Dextrinated Lead Azide

Examination of the current-voltage plots of the pressed dextrinated lead azide wafers (Fig 3-5) show that the current followed Ohm's law. However, either of two different current values could be obtained with reasonable precision for wafers of comparable thickness and length. One current value was about 50% larger than the other value. It is, however, not possible to predict at the outset which value would be realized by a given wafer. The reason for the two current values is unknown at this time. The resistivity of the pressed wafers ranged from $1-2 \times 10^{12}$ ohm-cm to $2-4 \times 10^{12}$ ohm-cm.

The plots also show that for the 0.080-cm-thick wafers, the current decreased as the density of the wafers was increased (Fig 3), but that the current remained the same for the 0.11-cm-thick wafer (Fig 4). When the density was kept constant at 3.45 g/ml, the current decreased as the thickness of the wafers was increased from 0.057 to 0.11 cm (Fig 5).

Electric Field Strength for Initiation of Pressed Dextrinated Lead Azide

The experimental data show that the electric field strengths for initiating pressed dextrinated lead azide wafers were a function of the density (Fig 6) and thickness (Fig 7). It can be seen in Figure 6 that as the density was increased from 2.7 to 3.75 g/ml, the average electric field strength decreased for the thinnest wafer tested (0.042 cm), remained practically constant for the 0.055-cm-thick wafers, and increased for the thicker wafers. Figure 7 shows that as the thickness of the wafer was increased from 0.04 to 0.11 cm, the electric field strength decreased at the lowest density tested (2.7 g/ml), did not change at a density of 2.95 g/ml, and increased at the higher densities (≥ 3.15 g/ml). The results also show (Fig 7) that the dielectric breakdown strength of air was generally higher than the electric field strength for initiating the pressed wafers, for thicknesses equal to or less than 0.07 cm. Hence, the presence of this explosive in electroexplosive devices can lower the voltage for pin-to-case breakdown and, thereby, give rise to an unexpected hazard.

Initiation by Joule Heating

Although it is not possible at this time to determine the initiation mechanism, it can be shown that initiation of the pressed dextrinated lead azide was not attributable to bulk Joule heating. The maximum power input to the pressed wafer, which exploded after 4 1/2 minutes, was approximately 3×10^{-6} watt (the current was in the 10^{-9} ampere range and the applied voltage was 3400 V). The maximum energy input up to the time of initiation was, therefore, of the order of 2×10^{-5} calorie. Neglecting all of the possible energy losses, the calculated temperature increase for the 50 mg pressed azide specimen would, therefore, be less than 0.1°K . This temperature increase is insufficient to cause thermal initiation.

It is possible that the temperature increase would have been much higher if the current density or the voltage drop had not been uniformly distributed. Three possible localized Joule heating situations were examined using the models described in Reference 2. The first situation assumed that the voltage dropped abruptly, that is, the voltage drop occurred across an infinitely thin plane parallel to the electrodes. However, calculations showed that, because of the rapid rate of thermal diffusion, thermal initiation by Joule heating was impossible. The maximum temperature rise calculated for the azide wafer, which exploded after 4 1/2 minutes, was about 0.05°K . The maximum temperature rise would have been less than 1°K for a 500 hour exposure. The model for the second situation assumed that all the current flowed in a narrow filament, a line source, through the explosive. Again, calculations showed that the experimental power input was insufficient to cause thermal initiation of the explosive since the temperature rise would have been less than 1°K for a one hour exposure. The third case assumed that all of the input was delivered to an infinitesimally small volume in the explosive. The model used for the calculations, although physically unrealistic, assumed a point source in an infinite medium. Calculations revealed that the temperature would have increased more than 100° within a radius of $4 \times 10^{-6} \text{cm}$ in nanoseconds. It was concluded, therefore, that thermal initiation by Joule heating was possible only in the third case and that explosion would occur in nanoseconds. However, since the times to initiation in the experimental tests were minutes and not nanoseconds, the possibility of this mechanism being responsible was disregarded. A value of $0.10 \text{ cal/g-}^\circ \text{K}$ and a value of $4.0 \times 10^{-4} \text{ cal/}^\circ \text{K-cm-sec}$ were used for the specific heat, c , and the thermal conductivity, k , of lead azide, respectively (Ref 8). The thermal diffusivity, K , was calculated from the equation $K = k/\rho c$, where ρ is the density of the explosive.

CONCLUSIONS

RD1333 lead azide became slightly more sensitive after repeated exposures to sub-threshold initiation levels of electric fields and this could, therefore, create some additional electrostatic hazard. This explosive was more electrostatically sensitive after being subjected to six cycles of either one-minute-on, one-minute-off or ten-minutes on, ten-minutes off applications of voltage but was unaffected after a constant long term exposure or being exposed to a pulsed electric field. Tetracene may have become slightly more sensitive after the six cycle application of voltage, but the results are inconclusive.

The average electric field strength required to initiate pressed dextrinated lead azide wafers was a function of the density and thickness of the wafer. This was generally less than the dielectric breakdown strength of air. Consequently, the presence of this explosive in electroexplosive devices could lower the voltage for pin-to-case breakdown and, thereby, give rise to an unexpected hazard.

Under the influence of an electric field, prebreakdown current will begin to flow through primary explosives after the electric field reaches a certain strength. The current will then increase as the voltage is increased according to Ohm's law. If the electric field is kept constant at strengths below and near the initiation levels, no significant current increase will occur with time under the described test conditions. These results do not reproduce those reported by Hanna and co-workers.

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